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INSULATOR DEPARTMENT

GENERAL ELECTRIC COMPANY

Technical Report No. LK-624-DR
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SUBJECT

INVESTIGATION OF EFFECT
OF
STEEP WAVE FRONT IMPULSES ON SUSPENSION INSULATORS

**RESTRICTED TO INSULATOR DEPARTMENT USE ONLY**

This report contains

12 Typewritten pages
6 Appendixes
2 Sketches
1 Drawing VRA-712-57

Signed Joseph Kaminski Jr    Approved Fred C. Vose

## I. INTRODUCTION

Reports of failures of a very serious nature on the systems of three important customers had been received. Investigations of failures occurring on one customer's system were carried on and reported in Technical Report No. 604. The above report in part concluded that, "the most likely cause of failure seems to be steep wave front surges of high amplitude."

The above investigations, as well as others carried out by the high voltage laboratory, appeared to have demonstrated, even though to a limited extent, the prevailing conditions existing on a transmission line at the time of failure. Areas in which close correlation appeared to exist between field and laboratory are:

1) Presence of steep wave front impulses initiating the flashover of strings.

2) Puncture of insulators in strings under steep wave front impulses.

3) Presence of high energy currents causing insulators to blow apart or pull apart under tensile loads.

4) Evidence of shell doughnutting under steep wave front impulses.

5) Evidence of depreciation of dielectric strength under steep wave front impulses.

In view of these apparent similarities an extensive program aimed at greater comprehension of the nature and mechanism producing such failures was undertaken.

## II. PROCEDURE

The accumulation of additional data was an essential step toward a better understanding of the problem. Therefore, the initial step in the investigation includes a program of comparative testing.

The following insulators from Insulator Dept., Ohio Brass, and Lapp were used:

| | | |
|---|---|---|
| OB #32440 | 15,000 lbs. | 5-3/4" spacing |
| Lapp #8200 | 15,000 lbs. | 5-3/4" spacing |
| Locke #1840 | 15,000 lbs. | 5-3/4" spacing |
| Locke #18425 | 25,000 lbs. | 5-3/4" spacing |
| *Locke #18254 | 25,000 lbs. | 5" spacing |
| *Locke #18360 | 36,000 lbs. | 5-3/4" spacing |

All steep wave front tests were made with the impulse generator having an energy input of 7000 watt seconds at 500-KV and an estimated surge current of approximately 7000 amps. ~~The wave shape used was the standard 1-1/2 x 40 microsecond impulse with flashovers occurring on the front of the wave at approximately 350 to 450 KV in 0.5 microseconds.~~ A tensile load of approximately 2000 lbs. was applied continuously to the insulator during the impulse flashover tests. (This above test method was used throughout the entire investigation.)

*Shells made from 304 high strength body.
(18254 previously numbered 18251)

Appendix A represents a compilation of tests on the previously listed insulators. Locke catalog insulators were all made under standard manufacturing practices with standard component hardware. It should be noted that while not reported the influence of insulator spacing, ball bolt style or type of suspension cap had no influence on the outcome of results.

A 60 cycle puncture under oil test was made without prior impulse testing on each group of insulators except OB #32440. This is shown in the report as having received zero impulses. The first two columns indicate the number of impulses and quantity of insulators receiving those number of impulses. The number of units punctured on the specific frequency of impulses is shown as column 3. Tabulated under the Puncture Under Oil heading is the individual values obtained in subsequent puncture under oil tests. The average is determined by totalling the puncture under oil values and dividing by the total number of units tested. For instance, if a unit punctured under impulse, its puncture under oil value would be zero. A measure of the quality of performance is shown in the final column listing the percent failing below 110 KV.

A review of the data with its accompanying summary establishes quite clearly the inferiority of Locke units to those of its competitors. In addition, the extremely poor performance demonstrated by the 18254 units would tend to reflect rather poorly on the 304 body. However, the 18360, made from the 304 body, rather closely parallels the performance of 18425 (both having same shell design 77598).

Insulators failing under impulse by breaking or shattering often exhibited the appearance of "doughnutting." "Doughnutting" of insulator shells is often associated with sudden or high impact loads. It was reasonable to assume either the presence of mechanical impact or high electrical impact during the overvoltage conditions. A series of tests were made on shells for the purpose of establishing either the presence of mechanical or electrical impact. These are reported in Appendix B and although no proof of impact was established it is interesting to note in most tests made with either pin or electrode held tight within the pinhole the failure rate is very high. The pattern of high failure for pins held securely is only altered with the addition of distilled water, molten lead, and mercury. The addition of mercury provided the greatest measure of relief from failure.

Next, all factors and materials related to the insulator shell were critically examined. Insulators were then assembled with shells in stages of completion and under different conditions of firing. It was hoped that by the process of elimination some critical feature of the shell could be established. The shells were prepared as follows:

- Group 1 - Fired without glaze and without sand.
- Group 2 - Fired and glazed but without sand on head or in pinhole.
- Group 3 - Fired and glazed with sand on head but not in pinhole.
- Group 4 - Fired and glazed with sand on head and in pinhole except at the bottom of the pinhole.
- Group 5 - Fired with glaze and sand on head; no glaze and sand in pinhole.
- Group 6 - Fired and glazed with no sand on head but sand in pinhole.
- Group 7 - Unglazed shell with sand on head and in pinhole (epoxy) resin used to bond sand to shell.
- Group 8 - Standard shell fired at bottom of Kiln No. 3.

Group 9 - Standard shell fired at top of Kiln No. 3
Group 10 - Standard shell fired in Kiln No. 2.
Group 11 - Standard shell fired in Kiln No. 1.

Appendix C is a tabulation of results for the above classifications. Under each classification the shell date and puncture value in KV, whether puncture occurred at base of cap or through the head, is shown. The pilot group are 60 cycle puncture tests made without the application of impulses. Under column heading KV and included in groups having received impulses, the letter "P" occasionally appears. This indicates the failure of the insulator occurred under the impulse test. Average KV and percent below 110-KV refer to only the units which have received prior impulse tests.

The significance of results achieved in this series of tests can be grasped almost immediately. A review of all the data focuses sharp attention to the effect sand, particularly its presence or absence in the pinhole, has on the impulse strength of the insulator. While removal of sand from the pinhole alleviates failures under steep wave front impulses it presents an impractical solution to the problem. The improvement shown by group 4, no sand in bottom of pinhole, when compared with groups 8, 9, 10, 11, 12 and the performance for the 1840 shown in Appendix A, provided material for further investigation.

In view of the exceedingly poor results obtained on 1840 shell style, 304 body 18254 insulators, it was of paramount importance to determine if the same factors were influencing both bodies. Five 1840-A3 shells (304 body) were taken from the Ceramic Lab. stock and fired. These were then assembled with component hardware and results are shown as Group 13 under Appendix D. Microscopic examination of fired 304 body particles indicated an abnormal amount of iron impurities. The chief source of this iron impurity was the alumina material used in the mix. Chemically pure alumina or alumina with very low iron content was purchased. Shells were made using chemically pure alumina in the body composition. Nothing else was changed and impulse tests on these insulators are shown as group 15 of Appendix D. In addition to the two aforementioned groups, group 14 standard 304 body and group 16 standard 304 body except without sand in the bottom of the pinhole are also shown.

Just as in the case of the 740 body, the presence or absence of sand in the pinhole was a decisive factor influencing the performance of the insulator under steep wave front impulses. Just by eliminating sand from the bottom of the pinhole the level of improvement when compared with 304 body insulators under Appendix A was as follows:

| | Ave. KV | % Below 110-KV |
|---|---|---|
| Appendix A (18254 old) | 49 | 93 |
| Appendix A (18254 new) | 57 | 100 |
| Appendix D | 124 | 10 |

The problem although isolated still provided many divergent paths which were not fully explored. Other questions which had to be resolved were:

1) The effect of acco-polymer or sand glaze additives used for adhesion of sand before firing. The possibility that some deleterious residues were forming after firing needed investigation.

2) Porosity of sand itself raised serious doubt since the addition of cement to an insulator provided a means whereby moisture might be absorbed into the sand, thereby providing highly conducting probes much in the manner of a needle point gap.

3) Laboratory examination of many kinds of sand seemingly indicated that certain characteristics might provide better grain structure and therefore each type must be more fully investigated.

Sand glaze and its adhesives covered in 1 above were tested and reported in Appendix E. Specific tests were made on:

Group 17 - Regular 7000 sand glaze in pinhole; sand on head and in pinhole.
Group 18 - Acco-polymer in pinhole; no sand in pinhole; sand on head.
Group 19 - Standard unit with Karo and glycol instead of acco-polymer in sand glaze.
Group 20 - Standard unit with 100% Karo in sand glaze.

Substituting Karo for acco-polymer does not benefit the insulator. Actually group 18 demonstrates that instead of acco-polymer accelerating failures, the absence of sand in the pinhole provides for an improvement in results.

To fully explore the effect of porosity and better grain structure in sand, a multiplicity of sands in the raw state, made from filter-pressed clays and prefired clays were prepared on shells and assembled into insulators and tested. Appendix F gives complete details and accompanying results with respect to these sands.

Several groups after initial testing gave indications of reasonably good results. Additional assemblies were made in the same manner and were subsequently tested and these same types did not come up to expectations. These groups were as follows:

| | INITIAL | | | REPEAT | | |
|---|---|---|---|---|---|---|
| | Group No. | Ave. | % | Group No. | Ave. | % |
| Prefired #3 Sand | 24 | 136 | 10 | 44 | 66 | 90 |
| Prefired Zircon Sand | 31 | 139 | 10 | 42 | 120 | 30 |
| Prefired Zircon Feldspar dry mix | 32 | 149 | 12.5 | 39 | 110 | 40 |

The sand exhibiting the most favorable qualities from the standpoint of steep wave front impulses was group 37, filter pressed zircon and feldspar combination. Also showing some promise was the prefired 317 clay and feldspar filter pressed body, group 36. Immediately following the impulse tests sufficient insulators were available to conduct M.&E. and Ultimate tests.

| Sample No. | Group 37 M.&E. Lbs. | Group 37 Ultimate Lbs. | Group 36 M.&E. Lbs. | Group 36 Ultimate Lbs. |
|---|---|---|---|---|
| 11 | 15800 | 24800 | 14200 | 16800 |
| 12 | 13150 | 23500 | 14300 | 18750 |
| 13 | 14850 | 19050 | 13050 | 15500 |
| 14 | 15250 | 16550 | 14000 | 14150 |
| 15 | 17500 | 22900 | 14300 | 18400 |
| 16 | 13600 | 21350 | 15150 | 18200 |
| 17 | 17000 | 19750 | 15250 | 18800 |
| 18 | 15200 | 22650 | 12800 | 18700 |
| 19 | 17600 | 19750 | 14000 | 14900 |
| 20 | 15400 | 18800 | 13600 | 17650 |
| Average | 15535 | 20910 | 14065 | 18800 |

Percent Below 15,000 - 40 ) Group 37    80 ) Group 36
Percent M.&E. Failures - 100 )    100 )

The poor performance of these sands on M.&E. precluded making additional tests.

Attached to Appendix F is a summary by types of sand. The performance shown is very erratic and substantially the same as shown in Appendix A for standard insulators. It is apparent that modifications to type as well as to manufacturing methods has not provided the desirable results. Sand exhibiting favorable characteristics toward impulse show extremely poor performance on M.&E. and Ultimate tests.

During a period when Manufacturing Engineering was experimenting with the automatic ball making machine and subsequently when automatic ball making equipment was in operation tests were made on shells produced under the experimental and final set ups with the following results:

PUNCTURE UNDER OIL AFTER 5 IMPULSES

| Experimental Ball Maker-Group 46 Shell Date | KV | Location | Automatic Production Ball Maker-Group 47 Shell Date | KV | Location |
|---|---|---|---|---|---|
| 02061 | 142 | H | 05222 | 152 | B.C. |
| 02061 | 136 | H | 05222 | 144 | H |
| 02061 | 106 | H | 05222 | 90 | H |
| 02061 | 144 | H | 05222 | 154 | H |
| 02061 | 80 | H | 05222 | 92 | H |
| 02061 | 153 | H | 05222 | 145 | H |
| 02061 | 88 | H | 05222 | 120 | H |
| 02061 | 140 | H | 05222 | 124 | H |
| 02061 | 150 | H | 05211 | 140 | H |
| 02061 | 82 | H | 05211 | 88 | H |
| Average - | 122 | | Average - | 125 | |

Percent Below 110-KV — 40---Group 46    30---Group 47

Automatic ball making does not relieve the situation but it certainly is not adversely effecting the performance of the insulator under steep wave front impulses.

In Appendix B when shells only were subjected to test, improved performance had been exhibited on shells using mercury and molten lead to secure the pinhole. Assuming the large conducting area prevalent in these assemblies was influencing the results on shells, insulators using 740 body and 304 body were assembled after having sprayed the bottoms of the pinhole generously with copper metal spray. These shells were sprayed with sand remaining in and on the bottom of the pinhole and it was believed that a better electrical distribution would result, such that concentration of electrical stress at the bottom pinhole radius would be relieved.

COPPER SPRAY BOTTOM PINHOLE

| 740 Body - Group 48 | | | 304 Body - Group 49 | | |
|---|---|---|---|---|---|
| Shell Date | KV | Location | Shell Date | KV | Location |
| 04011 | P | | 04181 | 40 | H |
| 04011 | 146 | H | 04181 | 74 | H |
| 04011 | 142 | H | 04181 | 66 | H |
| 04011 | 155 | H | 04181 | 80 | H |
| 04011 | 156 | H | 04181 | P | |
| 04011 | 162 | H | 04181 | P | |
| 04011 | 152 | H | 04181 | 72 | H |
| 04011 | 150 | H | 04181 | 134 | H |
| 04011 | P | | 04181 | 60 | H |
| 04011 | 156 | H | 04181 | 86 | H |
| Average - | 122 | | Average - | 61 | |

Percent Below 110-KV - 20---Group 48    90---Group 49

With the addition of copper metal spray to the bottom of the pinhole on the 740 body there appears to be some slight improvement in performance as compared to results in Appendix A. The improvement is not appreciable and the treatment is found ineffectual when results on the 304 body are taken into consideration.

Referring to Appendix C and D, results on assemblies without sand in the bottom of the pinhole provide material for further investigation. Therefore, shells of the 1840 style 740 body were made with the head thickness increased by approximately 1/16 of an inch and an absence of sand from the bottom of the pinhole. In addition to puncture under oil after impulse M.&E. and Ultimate tests were also made on these units.

NO SAND BOTTOM PINHOLE - INCREASED HEAD THICKNESS (Group 50)

Puncture After Impulse

| Shell Date | KV | Location |
|---|---|---|
| 02211 | 152 | H |
| 02211 | 142 | H |
| 02211 | 138 | H |
| 02211 | 170 | H |
| 02211 | 156 | H |
| 02211 | 170 | H |
| 02211 | 200 | H |
| 02211 | 150 | B.C. |
| 02211 | 109 | H |
| 02211 | 85 | H |
| 02211 | 164 | B.C. |
| 02211 | 144 | H |
| 02211 | 142 | H |
| 02211 | 175 | H |
| 02211 | 156 | H |
| 02211 | 180 | H |
| 02211 | 120 | H |
| 02211 | 120 | H |
| 02211 | 167 | H |

Average - 149

Percent Below 110-KV - 10.5

M.&E. and Ultimate (Pounds)

| Sample No. | M.&E. | Ultimate |
|---|---|---|
| 1 | 19600 | 22900 |
| 2 | 17500 | 19000 |
| 3 | 15800 | 15800 |
| 4 | 13700 | 21100 |
| 5 | 23850 | 23850 |
| 6 | 18950 | 18950 |
| 7 | 18250 | 19350 |
| 8 | 23000 | 23750 |
| 9 | 15600 | 20800 |
| 10 | 25700 | 25700 |
| 11 | 24550 | 24550 |
| 12 | 23300 | 23500 |
| 13 | 20250 | 20250 |
| 14 | 14200 | 16300 |
| Average - | 19590 | 21128 |

Percent Below 15,000 - 14.2
Percent Failing M.&E. - 50

The apparent improvement in puncture-impulse strength with the increased head thickness, no sand on bottom pinhole combination is offset by the relatively poor M.&E. results obtained on this lot of insulators. The high percentage of M.&E. failures preceeding mechanical failures can only be tolerated at the expense of a depreciation in the normal M.&E. and ultimate test level.

To seek some remedial measures for the disappointing M.&E. performance, it was conjectured that shells without sand in the bottom of the pinhole may be developing unusual voltage gradients at the bottom of the sand band and subsequently under the combined mechanical and electrical stress present electrical failures precipitated. It was thought that brushing sarco into the bottom of the pinhole might change the mechanical load distribution within the pinhole area and remove the high stress from the bottom of the pinhole. Assemblies with added head thickness, an absence of sand, and sarco brushed into the bottom of the pinhole, along with standard head thickness shells having no sand in the bottom of the pinhole, were tested and compared.

SHELLS INCREASED HEAD THICKNESS
NO SAND BOTTOM PINHOLE
SARCO BRUSHED BOTTOM PINHOLE

| Sample No. | M.&E. | Ultimate |
|---|---|---|
| 1 | 11300 | 11900 |
| 2 | 12400 | 12400 |
| 3 | 13300 | 13500 |
| 4 | 14400 | 14400 |
| 5 | 16000 | 16600 |
| 6 | 19550 | 19550 |
| 7 | 17150 | 17150 |
| 8 | 14150 | 14150 |
| 9 | 15200 | 16200 |
| 10 | 12000 | 12000 |
| Average - | 14545 | 14785 |

Percent Below 15,000 - 60
Percent Failing M.&E. - 40

SHELLS STANDARD HEAD THICKNESS
NO SAND AT BOTTOM OF PINHOLE

| Sample No. | M.&E. | Ultimate |
|---|---|---|
| 1 | 14050 | 15000 |
| 2 | 26850 | 26850 |
| 3 | 26950 | 26950 |
| 4 | 14200 | 19300 |
| 5 | 17550 | 18650 |
| 6 | 14900 | 21000 |
| 7 | 16150 | 22000 |
| 8 | 18200 | 18700 |
| Average - | 18606 | 21056 |

Percent Below 15,000 - 38
Percent Failing M.&E. - 75

Next, it was decided to make shells with the sand band on the outside below the plane of the sand band inside the pinhole (see sketch No. 1). Here again was an effort to redistribute stress away from the critical bottom of the pinhole. With the simultaneous application of load on both cap and pin and the absence of sand at the bottom of the pinhole, it seems very likely that an unbalanced load condition would exist. This unbalance is thought to be a tensile stress applied at the juncture of insulator head and sidewalls and created by the application of load from the lip of the cap transmitted through the sand band and applied from the cobb end of the pin to the sand on the pinhole.

LOWERED EXTERNAL SAND BAND

| Sample No. | M.&E. (Lbs.) | Ultimate (Lbs.) |
|---|---|---|
| 1 | 17900 | 21000 |
| 2 | 20700 | 21100 |
| 3 | 18350 | 18350 |
| 4 | 20800 | 21100 |
| 5 | 19800 | 19800 |
| 6 | 14400 | 24650 |
| 7 | 20650 | 20650 |
| 8 | 21650 | 21650 |
| 9 | 20950 | 20950 |
| 10 | 13800 | 19150 |
| Average | 18900 | 20840 |

Percent Below 15,000 - 20
Percent Failing M.&E. - 50

Since 50 percent of the assemblies failed electrically prior to mechanical failure, the previous supposition could not be supported.

The thought, however, persisted that stress distribution remained the stigma to providing good M.&E. performance with the removal of sand from the bottom of the pinhole. The attempt through lubrication or uniform distribution by the addition of sarco and the alteration of the external sand band to balance combined pin and cap loads had both failed to accomplish the intended purpose, just as the attempt to redistribute electrical stress by applying conducting coatings to the bottom of the pinhole had essentially failed to improve puncture-impulse performance.

Next, it was reasoned that the position of the ball bolt at the bottom of the pinhole was very critical. If this were true, then by placing a washer at the bottom of the pinhole approximately equal to the thickness of the removed sand the relationship of cap, pin, and pinhole radius would remain unchanged and subsequently no electrical preceeding mechanical failures should result.

This idea was put to a test by assembling insulators without sand in the bottom of the pinhole and an asphalt treated felt washer, 1/16 inches thick, placed on the bottom of the pinhole before assembling the pin. A second group identical to the first were dipped in wax.

The results achieved were:

| SHELLS, NO SAND BOTTOM PINHOLE ASPHALT WASHER BOTTOM PINHOLE | | | SHELLS, NO SAND BOTTOM PINHOLE ASPHALT WASHER BOTTOM PINHOLE HEADS WAXED | | |
|---|---|---|---|---|---|
| Sample No. | M.&E. (Pounds) | Ultimate (Pounds) | Sample No. | M.&E. (Pounds) | Ultimate (Pounds) |
| 1 | 19700 | 19700 | 1 | 19100 | 19100 |
| 2 | 23150 | 23150 | 2 | 20650 | 20650 |
| 3 | 21700 | 21700 | 3 | 19500 | 19500 |
| 4 | 21050 | 21050 | 4 | 21050 | 21050 |
| 5 | 20250 | 20250 | 5 | 21750 | 21750 |
| 6 | 21250 | 21250 | 6 | 21800 | 21800 |
| 7 | 21550 | 21550 | 7 | 19800 | 19800 |
| 8 | 21300 | 21300 | 8 | 21400 | 21400 |
| 9 | 21700 | 21700 | 9 | 22050 | 22050 |
| 10 | 22000 | 22000 | 10 | 21200 | 21200 |
| Average | - 21365 | 21365 | Average | - 20830 | 20830 |
| % Below 15,000 | 0 | 0 | | 0 | 0 |
| % M.&E. Failures | 0 | 0 | | 0 | 0 |

The addition of the asphalt washer has produced the desired result. Twenty assemblies tested without failure below 15,000 lbs. and without electrical failures preceeding mechanical failures.

Further demonstration of proof by removing sand from the bottom of the pinhole and adding an asphalt washer to maintain M.&E. strength is shown by the following tests made on 304 body shells. Preceeding the M.&E. data is Puncture Under Oil After 5 Impulses for 18255 assemblies using the 304 body with no sand in the pinhole but an ashphalt washer at the bottom of the pinhole.

PUNCTURE UNDER OIL AFTER 5 IMPULSES

| KV | Location | KV | Location |
|---|---|---|---|
| 156 | B.C. | 130 | H |
| 85 | H | 160 | B.C. |
| 140 | B.C. | 92 | H |
| 156 | H | 162 | B.C. |
| 144 | B.C. | 85 | H |

Average - 131

Percent Below 110-KV - 30

18255 Assembly

NO SAND BOTTOM PINHOLE
NO ASPHALT WASHER

| Sample No. | M.&E. (Pounds) | Ultimate (Pounds) |
|---|---|---|
| 1 | 26650 | 32100 |
| 2 | 27500 | 33700 |
| 3 | 29600 | 29600 |
| 4 | 32100 | 32100 |
| 5 | 22450 | 33450 |
| 6 | 28850 | 28850 |
| 7 | 30100 | 30100 |
| 8 | 31250 | 31250 |
| 9 | 26850 | 26850 |
| 10 | 28250 | 28250 |
| Average | 28360 | 30625 |

Percent Below 25,000 lbs. - 10
Percent M.&E. Failures - 30

18255 Assembly

NO SAND BOTTOM PINHOLE
ASPHALT WASHER ADDED

| Sample No. | M.&E. (Pounds) | Ultimate (Pounds) |
|---|---|---|
| 1 | 30100 | 30100 |
| 2 | 26100 | 26100 |
| 3 | 28100 | 28100 |
| 4 | 27550 | 27550 |
| 5 | 29850 | 29850 |
| 6 | 30700 | 30700 |
| 7 | 27100 | 27100 |
| 8 | 31850 | 31850 |
| 9 | 30700 | 30700 |
| 10 | 34500 | 34500 |
| Average | 29655 | 29655 |

Percent Below 25,000 lbs. - 0
Percent M.&E. Failures - 0

## III. SUMMARY

Improvement in insulator performance under steep wave front impulses is substantial on insulators having sand removed from the bottom of the pinhole. This is particularly true on 1840 style shells made from the 304 body. For further evidence a resume of all puncture under oil tests after five impulses made during the investigation shows:

| | 1840 Style 740 Body | | 1840 Style 304 Body | |
|---|---|---|---|---|
| | Standard Assemblies | Without sand bottom pinhole | Standard Assemblies | Without sand bottom pinhole |
| Total tested | 60 | 29 | 30 | 20 |
| Average KV | 115 | 142 | 61 | 128 |
| % Below 110-KV | 35 | 15 | 97 | 20 |

It is to be noted that while improvement is in positive evidence, complete improvement has not been achieved. Many of the insulators which failed were examined critically; these examinations included porosity, specific gravity, and microscopic examinations. These examinations did not provide any evidence for establishing the pattern of failure. It was of interest to observe that the puncture path in units examined after puncture under oil tests and also in the units failing electrically prior to mechanical failure in the M.&E. test were in the same general area. The attached sketch No. 2 shows the location of these puncture paths. Examination of the sketch shows that the failure originates at the sharp edge of the cobb end of the pin and in the small internal radius at the bottom of the pinhole.

It is reasonable to assume that the small radius between the step of the head and sidewalls provide an area of high electrical field concentration. The same concentration will occur at the edge of the sharp corner of the ball bolt. The placement of pin in the pinhole as required in suspension insulator assemblies makes this area vulnerable to electrical field concentrations.

Similar concentrations of stress will occur through mechanical stress distribution of radii and sharp edges of ball bolts with the application of loads.

The effect of the presence or absence of sand in this area can then only lead to further supposition. It is conjectured that when sand particles of varying shapes and sizes are placed in this zone of high mechanical and electrical stress, the orientation of certain particles with respect to steep wave front impulses follows the behaviour of needle point electrodes promoting even greater electrical stress concentrations which subsequently lead to insulator breakdown.

The application of the above reasoning while explaining the cause of breakdown does not provide an explanation of why 304 body insulators with sand located at the bottom of the pinhole are more susceptible to breakdown under impulse than those of the 740 body. Referring back to Appendix B, it will be recalled that the pattern of breakdown was greatest on shells in which electrodes were held more rigidly in place. It may be possible that the adhesion of sand to the 304 body is somewhat greater than the adhesion of sand to the 740 body and hence the presence of a multiplicity of rigidly held electrodes provides the mechanism for promoting this higher degree of failure.

By removing the sand from the bottom of the pinhole and then subjecting insulators to combined mechanical and electrical tests, a higher percentage of electrical failures occurs. Improvement is immediate if a washer of thickness roughly comparable to the removed sand is placed in the bottom of the pinhole. This undoubtedly reflects on the sensitivity of the critical zone. Moving the pin toward the bottom of the pinhole places both greater mechanical and electrical stress in the vulnerable pinhole radius, and the subsequent application of load results in electrical failure.

Examination of insulators which failed impulse tests but are reported as having sand removed from bottom of pinhole always had clusters of sand particles adhering to a portion of the pinhole radius. More effective sand removal may have led to even greater improvement in performance.

IV. CONCLUSIONS

Immediate improvement in insulator performance under steep wave front impulse surges without detrimental effect when subjected to combined mechanical and electrical loads may be obtained by removing the sand from the bottom of the pinhole and adding a small asphalt washer. It is important to note that the removal of sand from the bottom of the pinhole includes removal of sand from the internal radius. This may be done by instructing glaze wheel operators to avoid brushing acco-polymer below a certain location within the pinhole and adjusting the squirt nozzle to prevent flushing the bottom of the pinhole with glaze. Also, when transporting shells to the kiln, glaze will tend to run down across the internal radius and sand particles shaken loose by vibration will become lodged in the radius. Kiln loaders should be instructed to upset shell and attempt to shake free sand loose. This method will not result in complete freedom from failure but will certainly lead to improved results.

From a long range standpoint much additional work needs to be carried out. For instance, a slight increase in head thickness (Group 50) elevated the individual puncture values in most cases to extremely high values. Lower concentration factors may be obtained by providing a larger radius at the bottom of the pinhole and some further improvement may be gained by increasing the radius of curvature at the top of the head. To further reduce the stress concentrations within the pinhole, it is believed desirable to increase the present radius at the edge of the cobb end of the ball bolt from the present 1/32" to 1/8".

A composite of all these recommended changes is shown on drawing VR-A-712-57.

JKaminski/cp
7/3/57

## APPENDIX A



| Insulator Designation | No. of Impulses | Qty. Tested | Qty. Punctured | Puncture Under Oil, KV | | | | | | | | | | Ave. KV | Percent Below 110-KV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1840 | 0 | 5 | - | 136 | 146 | 150 | 150 | 150 | | | | | | 146 | 0 |
| | 1 | 10 | - | 126 | 130 | 134 | 142 | 145 | 146 | 146 | 150 | 150 | 165 | 143 | 0 |
| | 2 | 10 | - | 92 | 138 | 139 | 150 | 150 | 153 | 154 | 155 | 156 | 160 | 145 | 10 |
| | 3 | 20 | - | 91 | 107 | 110 | 120 | 120 | 126 | 130 | 136 | 136 | 138 | | |
| | | | | 140 | 142 | 143 | 148 | 148 | 150 | 152 | 156 | 156 | 86 | 131 | 15 |
| | 4 | 19 | 1 | 80 | 80 | 84 | 112 | 126 | 132 | 134 | 136 | 136 | 140 | | |
| | | | | 140 | 140 | 148 | 150 | 150 | 150 | 154 | 156 | | | 126 | 22.2 |
| | 5 | 20 | 4 | 76 | 80 | 80 | 80 | 80 | 81 | 88 | 128 | 130 | 132 | | |
| | | | | 140 | 146 | 150 | 150 | 156 | 156 | | | | | 93 | 55 |
| 18425 | 0 | 5 | - | 128 | 136 | 150 | 154 | 156 | | | | | | 145 | 0 |
| | 1 | 10 | - | 136 | 156 | 156 | 156 | 156 | 156 | 160 | 160 | 170 | 170 | 158 | 0 |
| | 2 | 10 | - | 83 | 90 | 100 | 105 | 120 | 152 | 155 | 160 | 178 | 180 | 132 | 40 |
| | 3 | 10 | - | 90 | 112 | 132 | 145 | 146 | 148 | 150 | 154 | 156 | 160 | 139 | 10 |
| | 4 | 10 | - | 106 | 140 | 142 | 145 | 146 | 146 | 148 | 150 | 152 | 155 | 143 | 10 |
| | 5 | 20 | - | 80 | 85 | 106 | 110 | 110 | 120 | 132 | 140 | 146 | 150 | | |
| | | | | 154 | 154 | 156 | 156 | 156 | 156 | 156 | 156 | 156 | 170 | 137 | 15 |

| Insulator Designation | No. of Impulses | Qty. Tested | Qty. Punctured | Puncture Under Oil, KV | Ave. KV | Percent Below 110-KV |
|---|---|---|---|---|---|---|
| AB #32440 | 0 | - | - | | | |
| | 1 | - | - | | | |
| | 2 | - | - | | | |
| | 3 | - | - | | | |
| | 4 | - | - | | | |
| | 5 | 10 | 0 | 80 140 140 144 146 150 152 152 154 156 | 141 | 10 |
| Lapp #8200 | 0 | 3 | 0 | 146 150 150 | 148 | 0 |
| | 1 | - | - | | | |
| | 2 | - | - | | | |
| | 3 | - | - | | | |
| | 4 | - | - | | | |
| | 5 | 18 | 0 | 146 143 150 150 150 154 154 154 156 156<br>156 156 156 156 156 156 165 165 | 154 | 0 |
| 18254 From Old Stock | 0 | 10 | 0 | 120 140 140 141 144 146 148 150 156 156 | 144 | 0 |
| | 1 | 10 | 0 | 80 83 83 90 98 102 109 127 140 148 | 97 | 70 |
| | 2 | 10 | 0 | 73 76 77 78 80 84 85 120 130 148 | 95 | 70 |
| | 3 | 15 | 0 | 59 62 64 69 70 70 70 74 78 92<br>93 120 138 140 146 | 90 | 73 |
| | 4 | 14 | 0 | 31 43 65 68 70 71 74 78 82 82<br>84 130 140 146 | 83 | 79 |
| | 5 | 15 | 4 | 32 36 59 63 63 65 68 72 79 80<br>117 | 49 | 93 |

| Insulator Designation | No. of Impulses | Qty. Tested | Qty. Punctured | Puncture Under Oil, KV | | | | | | | | | | Ave. KV | Percent Below 110-KV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18254 From New Stock | 0 | 5 | 0 | 144 | 144 | 144 | 144 | 148 | | | | | | 145 | 0 |
| | 1 | 10 | 0 | 80 | 82 | 88 | 89 | 110 | 122 | 130 | 132 | 140 | 150 | 123 | 40 |
| | 2 | 10 | 0 | 61 | 77 | 77 | 79 | 79 | 81 | 81 | 90 | 112 | 150 | 89 | 80 |
| | 3 | 10 | 0 | 78 | 78 | 82 | 90 | 97 | 102 | 142 | 142 | 150 | 153 | 111 | 60 |
| | 4 | 10 | 1 | 68 | 78 | 80 | 80 | 80 | 84 | 84 | 86 | 146 | | 79 | 90 |
| | 5 | 10 | 2 | 60 | 62 | 64 | 70 | 74 | 76 | 78 | 90 | | | 57 | 100 |
| 18360 | 0 | 5 | 0 | 132 | 136 | 150 | 150 | 150 | | | | | | 143 | 0 |
| | 1 | 10 | 1 | 90 | 104 | 106 | 108 | 126 | 134 | 134 | 142 | 142 | | 108 | 40 |
| | 2 | 10 | 0 | 80 | 80 | 82 | 112 | 130 | 134 | 144 | 150 | 150 | 156 | 122 | 30 |
| | 3 | 10 | 0 | 80 | 82 | 84 | 128 | 130 | 130 | 138 | 146 | 148 | 154 | 122 | 30 |
| | 4 | 10 | 0 | 84 | 92 | 110 | 120 | 142 | 146 | 150 | 150 | 156 | 170 | 132 | 20 |
| | 5 | 10 | 0 | 82 | 85 | 120 | 124 | 140 | 144 | 146 | 150 | 150 | 150 | 129 | 20 |

## Summary

| | 1840 | 18425 | OB #3244C | Lapp #8200 | 18254 (old) | 18254 (new) | 18360 |
|---|---|---|---|---|---|---|---|
| Average Puncture (KV) Under Oil after 5 impulses | 93 | 137 | 141 | 154 | 49 | 57 | 129 |
| Percent Below 110-KV after 5 impulses | 55 | 15 | 10 | 0 | 93 | 100 | 20 |

## 1840 SHELLS (UNLESS OTHERWISE NOTED)

Number of impulses applied to failure (Limit - 20 impulses)

| Sample No. | Pin set in molten lead in pinhole | 77598 shell with pin set loosely in pinhole (92674 pin) | Pin set in pinhole with mercury added | 18400 shell with pin loosely set in pinhole and faschine dye added |
|---|---|---|---|---|
| 1 | 20 | 6 | 20 | A 10 |
| 2 | 20 | 4 | 20 | A 10 |
| 3 | 20 | 5 | 20 | A 10 |
| 4 | 20 | 11 | 20 | A 10 |
| 5 | 5 | 15 | 20 | A 10 |
| 6 | 7 | - | 20 | - |

Number of impulses applied to failure (Limit - 20 impulses)

| Sample No. | 18400 shell pin set loosely in pinhole, zyglo added | 77598 shell with 18425-P pin set loosely in pinhole | 18400 shell with 73991-1 pin set in pinhole with zyglo added | Pin set in pinhole with zinc metalspray added to pinhole |
|---|---|---|---|---|
| 1 | B 10 | C 10 | D 3 | E 10 |
| 2 | B 10 | C 10 | D 2 | E 4 |
| 3 | B 8 | C 10 | D 2 | E 4 |
| 4 | B 2 | C 7 | D 2 | E 6 |
| 5 | B 2 | C 10 | D 10 | E 5 |

A - No dye penetration
B - Possibly slight penetration of zyglo
C - No penetration of zyglo
ABCDE - Maximum number of impulses - 10

APPENDIX C



## ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 1 | | | GROUP 2 | | | GROUP 3 | | | GROUP 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plain shell, no sand, no glaze | | | Shell glaze, no sand on head or in pinhole | | | Shell glazed, sand on head, no sand in pinhole | | | Glazed, sand on head, sand in pinhole, no sand in bottom of pinhole | | |
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | 02062 | 165 | B.C. | 02052 | 165 | B.C. | 02052 | 168 | B.C. | 02052 | 150 | H |
| | 02062 | 152 | B.C. | 02052 | 144 | B.C. | 02052 | 170 | B.C | 02052 | 138 | B.C. |
| | 02062 | 156 | H | 02051 | 150 | B.C. | 02052 | 146 | B.C. | 02052 | 148 | B.C. |
| | 02062 | 160 | B.C. | 02051 | 152 | B.C. | 02052 | 178 | B.C. | 02052 | 152 | B.C. |
| | 02062 | 160 | H | 02051 | 148 | B.C. | 02052 | 165 | B.C. | 02052 | 150 | B.C. |
| Puncture Under Oil after 5 impulses | 02062 | 156 | B.C. | 02052 | 142 | B.C. | 02052 | P | B.C. | 02082 | 160 | B.C. |
| | 02062 | 178 | H | 02052 | 148 | B.C. | 02052 | 168 | B.C. | 02082 | 102 | B.C. |
| | 02062 | 160 | B.C. | 02052 | 155 | B.C. | 02052 | 150 | B.C. | 02082 | 140 | H |
| | 02062 | 160 | B.C. | 02052 | 156 | B.C. | 02056 | 154 | B.C. | 02082 | 160 | B.C |
| | 02062 | 165 | H | 02052 | 163 | B.C. | 02052 | 165 | H | 02082 | 150 | B.C. |
| | 02062 | 168 | B.C. | 02052 | 155 | B.C. | 02052 | 164 | B.C. | 02082 | 140 | B.C. |
| | 02062 | 160 | B.C. | 02052 | 150 | B.C. | 02052 | 160 | B.C. | 02082 | 45 | [illegible] |
| | 02062 | 135 | H | 02052 | 152 | B.C. | 02052 | 165 | B.C. | 02082 | 146 | [illegible] |
| | 02062 | 170 | H | 02052 | 160 | B.C. | 02052 | 148 | B.C. | 02082 | 156 | [illegible] |
| | 02062 | 165 | H | 02052 | 140 | B.C. | 02052 | 165 | B.C. | 02082 | 150 | [illegible] |
| Ave. KV | | 162 | | | 152 | | | 144 | | | 135 | |
| % Below 110-KV | | 0 | | | 0 | | | 10 | | | 20 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

APPENDIX C



ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 5 | | | GROUP 6 | | | GROUP 7 | | | GROUP 8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Head glazed and sanded, Pinhole unglazed, unsanded | | | Glazed, no sand on head, Sand in pinhole | | | Unglazed, sand on head and in pinhole | | | Standard shell fired Bottom Kiln No. 3 | | |
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | 02052 | 145 | B.C. | 02052 | 164 | H | 02132 | 114 | H | - | - | - |
| | 02052 | 150 | B.C. | 02052 | 146 | H | 02132 | 110 | H | - | - | - |
| | 02052 | 142 | H | 02052 | 150 | H | 02132 | 122 | H | - | - | - |
| | 02052 | 150 | B.C. | 02052 | 145 | B.C | 02132 | 104 | H | - | - | - |
| | 02052 | 153 | B.C. | 02052 | 150 | B.C. | - | - | - | - | - | - |
| Puncture Under Oil after 5 impulses | 02052 | 144 | B.C. | 02052 | P | - | 02130 | 41 | H | 01201 | 79 | H |
| | 02052 | 150 | B.C. | 02052 | 142 | H | 02130 | P | - | 01201 | 155 | H |
| | 02052 | 160 | H | 02052 | P | - | 02130 | P | - | 01201 | 144 | H |
| | 02052 | 174 | H | 02052 | 152 | H | 02130 | P | - | 01201 | 156 | B.C. |
| | 02052 | 152 | H | 02052 | 156 | B.C. | 02130 | P | - | 01242 | 79 | H |
| | 02052 | 142 | H | 02052 | 98 | H | 02130 | P | - | 01242 | 150 | B.C. |
| | 02052 | 158 | H | 02052 | 95 | H | - | - | - | 01242 | 102 | H |
| | 02052 | 140 | H | 02052 | P | - | - | - | - | 01242 | 142 | H |
| | 02052 | 140 | B.C. | 02052 | 80 | H | - | - | - | 01242 | 142 | H |
| | 02052 | 140 | H | 02052 | P | - | - | - | - | 01242 | 79 | H |
| Ave. KV | | 150 | | | 72 | | | 7 | | | 123 | |
| % Below 110-KV | | 0 | | | 70 | | | 100 | | | 40 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

## ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 9 Standard shell fired Top Kiln No. 3 | | | GROUP 10 Standard shell fired In Kiln No.2 | | | GROUP 11 Standard shell fired In Kiln No. 1 | | | GROUP 12 Standard shell Sponged pinhole | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | - | - | - | - | - | - | - | - | - | 02051 | 145 | - |
| | - | - | - | - | - | - | - | - | - | 02051 | 148 | - |
| | - | - | - | - | - | - | - | - | - | 02051 | 153 | - |
| | - | - | - | - | - | - | - | - | - | 02051 | 145 | - |
| | - | - | - | - | - | - | - | - | - | 02051 | 152 | - |
| Puncture Under Oil after 5 impulses | 01302 | 130 | H | 02052 | 133 | H | 02041 | 128 | H | 02051 | 78 | - |
| | 01292 | 140 | H | 02052 | 68 | H | 02041 | 120 | H | 02051 | 110 | - |
| | 01292 | 120 | H | 02052 | 150 | B.C. | 01242 | 86 | H | 02051 | 100 | - |
| | 01302 | 124 | H | 02052 | 146 | B.C. | 01312 | 112 | H | 02051 | 140 | - |
| | 01302 | 88 | H | 02052 | 140 | H | 02042 | 57 | H | 02051 | 136 | |
| | 01282 | 150 | H | 02052 | 80 | H | 02052 | 160 | H | 02051 | P | - |
| | 01301 | 145 | H | 02052 | 122 | H | 01311 | 150 | H | 02051 | 80 | - |
| | 01301 | 83 | H | 02052 | 75 | H | 02042 | 146 | H | 02051 | 90 | - |
| | 01292 | 152 | B.C. | 02052 | 120 | H | 02041 | 150 | H | 02051 | 60 | - |
| | 01292 | 128 | H | 02052 | 123 | H | 01301 | 78 | H | 02051 | 138 | - |
| Ave. KV | | 126 | | | 116 | | | 119 | | | 93 | |
| % Below 110-KV | | 20 | | | 30 | | | 30 | | | 60 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

## APPENDIX E



### ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 17 Standard with regular 7000 glaze in pinhole | | | GROUP 18 Acco-polymer in pinhole No sand in pinhole | | | GROUP 19 Standard unit with Karo and Glycol sand glaze | | | GROUP 20 100% Karo and sand glaze | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | 02182 | 108 | H | 02192 | 140 | B.C. | 02151 | 152 | B.C. | 02132 | 123 | H |
| | 02182 | 116 | H | 02192 | 138 | B.C. | 02151 | 140 | H | 02132 | 128 | H |
| | 02182 | 152 | B.C. | 02192 | 156 | B.C. | 02151 | 140 | H | 02132 | 140 | B.C. |
| | 02182 | 156 | B.C. | 02192 | 148 | B.C. | 02151 | 141 | H | 02132 | 151 | B.C. |
| | 02182 | 144 | B.C. | 02192 | 156 | B.C. | 02152 | 155 | B.C. | 02132 | 146 | B.C. |
| Puncture Under Oil after 5 impulses | 02182 | 105 | H | 02192 | 152 | B.C. | 02151 | 134 | H | 02132 | 80 | H |
| | 02182 | 147 | B.C. | 02192 | 80 | H | 02151 | 156 | B.C. | 02132 | 150 | H |
| | 02182 | 100 | H | 2192 | 152 | B.C. | 02151 | 90 | H | 02132 | 149 | H |
| | 02182 | 156 | H | 02192 | 135 | H | 02151 | 126 | H | 02132 | P | - |
| | 02182 | 121 | H | 02192 | 143 | B.C. | 02151 | 150 | B.C. | 02132 | 146 | H |
| | 02182 | 144 | B.C. | 02192 | 146 | H | 02151 | 146 | H | 02132 | 116 | H |
| | 02182 | 75 | H | 02192 | 145 | B.C. | 02151 | 73 | H | 02132 | 45 | H |
| | 02182 | 140 | H | 02192 | 109 | H | 02151 | 100 | H | 02132 | 73 | H |
| | 02182 | 73 | H | 02192 | 150 | B.C. | 02151 | P | - | 02132 | 112 | H |
| | 02182 | P | - | 02192 | 146 | B.C. | 02151 | P | - | 02132 | 78 | H |
| Ave. KV | | 106 | | | 136 | | | 97.5 | | | 95 | |
| % Below 110-KV | | 50 | | | 20 | | | 50 | | | 50 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

## APPENDIX F



### ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 21 No. 1 Zircon sand in pinhole | | | GROUP 22 Porcelain sand in pinhole | | | GROUP 23 Alumina Sand No. 2 in pinhole | | | GROUP 24 Prefired #3 sand in pinhole and on head | | | GROUP 25 Prefired 740-1 sand in pinhole | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Locatio |
| Pilot Group | 02131 | 145 | H | 02182 | 136 | H | 02182 | 136 | H | 02182 | 140 | H | - | - | - |
| | 02131 | 150 | H | 02182 | 140 | H | 02182 | 150 | B.C. | 02201 | 153 | H | - | - | - |
| | 02131 | 123 | H | 02182 | 121 | H | 02182 | 126 | H | 02201 | 136 | H | - | - | - |
| | 02131 | 146 | H | 02182 | 145 | H | 02182 | 142 | H | 02201 | 150 | B.C. | - | - | - |
| | 02131 | 143 | H | 02182 | 142 | B.C. | 02182 | 144 | B.C. | 02201 | 144 | B.C. | - | - | - |
| Puncture Under Oil after 5 impulses | 02131 | 149 | H | 02182 | 140 | H | 02182 | 138 | H | 02202 | 150 | B.C. | 02281 | 79 | H |
| | 02131 | 116 | H | 02182 | 130 | H | 02182 | 154 | H | 02202 | 152 | B.C. | 02281 | 71 | H |
| | 02131 | 140 | H | 02182 | P | - | 02182 | P | - | 02202 | 154 | H | 02281 | 136 | H |
| | 02131 | 80 | H | 02182 | 115 | H | 02182 | P | - | 02202 | 86 | H | 02281 | 71 | H |
| | 02131 | 150 | H | 02182 | 104 | H | 02182 | 75 | H | 02202 | 145 | H | 02281 | 144 | H |
| | 02131 | 71 | H | 02182 | 150 | H | 02182 | 69 | H | 02202 | 152 | B.C. | 02281 | 79 | H |
| | 02131 | 156 | B.C. | 02182 | 71 | H | 02182 | 72 | H | 02202 | 122 | H | 02281 | P | - |
| | 02131 | 165 | B.C. | 02182 | 150 | B.C. | 02182 | 134 | H | 02202 | 126 | H | 02281 | 61 | H |
| | 02131 | 80 | H | 02182 | 78 | H | 02182 | 73 | H | 02202 | 129 | H | 02281 | 114 | H |
| | 02131 | 150 | H | 02182 | 78 | H | 02182 | P | - | 02202 | 146 | B.C. | 02281 | 145 | B.C. |
| Ave. KV | | 125 | | | 102 | | | 72 | | | 136 | | | 90 | |
| % Below 110-KV | | 30 | | | 50 | | | 70 | | | 10 | | | 60 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 26 | | | GROUP 27 | | | GROUP 28 (18400 Shells) | | | GROUP 29 | | | GROUP 30 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw No. 317 WG2 sand in pinhole | | | Raw Zircon sand | | | Raw Beryl sand in pinhole | | | Raw Zircon and Feld-spar mixed in pinhole | | | Prefired 317 sand in pinhole | | |
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | - | - | - | 03021 | 136 | H | 03081 | 136 | H | 03081 | 170 | B.C. | 03051 | 120 | H |
| | - | - | - | 03031 | 114 | H | 03081 | 140 | H | 03081 | 146 | H | 03051 | 172 | H |
| | - | - | - | 02031 | 132 | H | 03081 | 136 | H | 03081 | 146 | H | 03051 | 138 | H |
| | - | - | - | 03031 | 154 | H | 03081 | 116 | H | 03081 | 156 | B.C. | 03051 | 145 | H |
| | - | - | - | 03031 | 140 | H | 03081 | 115 | H | 03081 | 148 | B.C. | 03051 | 156 | H |
| Puncture Under Oil after 5 impulses | 02281 | 150 | H | 03031 | 53 | - | 03081 | 82 | H | 03081 | 80 | H | 03051 | P | - |
| | 02281 | 155 | B.C. | 03031 | 80 | - | 03081 | P | - | 03081 | 148 | H | 03051 | 142 | H |
| | 02281 | 35 | H | 03031 | 114 | - | 03081 | P | - | 03081 | 91 | H | 03051 | 84 | H |
| | 02281 | 150 | H | 03031 | 140 | - | 02081 | P | - | 03081 | 162 | B.C. | 03051 | P | - |
| | 02281 | P | - | 03031 | 106 | - | 03081 | P | - | 03081 | 101 | H | 03051 | 154 | B.C. |
| | 02281 | 162 | B.C. | 03031 | 80 | - | 03081 | 122 | H | 03081 | 140 | H | 03051 | 152 | H |
| | 02281 | 145 | H | 03031 | 78 | - | 03081 | 72 | H | 03081 | 165 | H | 03051 | 128 | H |
| | 02281 | 148 | H | 03031 | 152 | - | 03081 | 77 | H | 03081 | 150 | H | 03051 | 110 | H |
| | 02281 | 165 | H | 03031 | 152 | - | 03081 | 74 | H | 03081 | 80 | H | 03051 | P | - |
| | 02281 | 140 | H | 03031 | 108 | - | 03081 | 40 | H | 03081 | 130 | H | 03051 | 41 | H |
| Ave. KV | | 125 | | | 100 | | | 47 | | | 125 | | | 81 | |
| % Below 110-KV | | 20 | | | 60 | | | 90 | | | 40 | | | 50 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

## ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 31 Prefired Zircon sand in pinhole | | | GROUP 32 Prefired Zircon Feld-spar dry mix in pinhole | | | GROUP 33 Prefired Beryl sand in pinhole | | | GROUP 34 Beryl prefired filter pressed sand in pinhole | | | GROUP 35 #3 sand prefired, filt pressed in pinhole | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Pilot Group | | 154 | B.C. | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 154 | H | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 132 | H | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 156 | B.C. | - | - | - | - | - | - | - | - | - | - | - | - |
| | | 145 | B.C. | - | - | - | - | - | - | - | - | - | - | - | - |
| Puncture Under Oil after 5 impulses | 03122 | 150 | B.C. | 03122 | 91 | H | 03122 | 82 | H | 04012 | 82 | H | 04012 | 80 | H |
| | 03122 | 152 | H | 03122 | 165 | B.C. | 03122 | 168 | H | 04012 | 78 | H | 04012 | 83 | H |
| | 03122 | 140 | H | 03122 | 156 | H | 03122 | 142 | H | 04012 | 138 | H | 04012 | 79 | H |
| | 03122 | 170 | B.C. | 03122 | 170 | H | 03122 | 150 | H | 04012 | 80 | H | 04012 | 98 | H |
| | 03122 | 144 | H | 03122 | 155 | H | 03122 | 80 | H | 04012 | P | - | 04012 | 67 | H |
| | 03122 | 90 | H | 03122 | 145 | H | 03122 | 136 | H | 04012 | P | - | 04012 | 122 | H |
| | 03122 | 130 | H | 03122 | 156 | B.C. | 03122 | 83 | H | 04012 | 101 | H | 04012 | 144 | B.C. |
| | 03122 | 140 | H | 03122 | 153 | B.C. | 03122 | 84 | H | 04012 | 165 | H | 04012 | 98 | H |
| | 03122 | 132 | H | - | - | - | 03122 | 146 | H | 04012 | P | - | 04012 | 50 | H |
| | 03122 | 145 | H | - | - | - | 03122 | 165 | H | 04012 | 80 | H | 04012 | 140 | H |
| Ave. KV | | 139 | | | 149 | | | 124 | | | 72 | | | 96 | |
| % Below 110-KV | | 10 | | | 12.5 | | | 40 | | | 80 | | | 70 | |

H - Head
B.C. - Base of Cap
P - Puncture under impulse

## ALL SHELLS 1840 STYLE 740 BODY

| | GROUP 36 | | | GROUP 37 | | | GROUP 38 | | | GROUP 39 | | | GROUP 40 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 317 and Feldspar prefired and filter pressed in pinhole | | | Zircon and Feldspar filter pressed in pinhole | | | Prefired 45% Beryl Porcelain in pinhole, dry mix | | | 317 Zircon and Feldspar prefired, dry mix, in pinhole | | | 45% Raw Beryl porcelain in pinhole | | |
| | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location | Shell Date | KV | Location |
| Puncture Under Oil after 5 impulses | 04012 | 170 | B.C. | 03281 | 149 | H | 03201 | 156 | H | 03281 | 40 | H | 03281 | P | - |
| | 04012 | 63 | H | 03281 | 151 | H | 03201 | 80 | H | 03281 | 152 | H | 03281 | P | - |
| | 04012 | 148 | H | 03281 | 170 | B.C. | C3201 | 119 | H | 03281 | 78 | H | 03281 | 135 | H |
| | 04012 | 152 | H | 03281 | 156 | H | 03201 | 80 | H | 03281 | 76 | H | 03281 | 78 | H |
| | 04012 | 69 | H | 03281 | 165 | B.C. | 03201 | 78 | H | 03281 | 90 | H | 03281 | 140 | B.C. |
| | 04012 | 150 | H | 03281 | 144 | H | 03201 | 61 | H | 03281 | 154 | H | C3281 | 125 | H |
| | 04012 | 170 | H | 03281 | 155 | H | 03201 | 69 | H | 03281 | 130 | H | 03281 | 76 | H |
| | 04012 | 150 | H | 03281 | 147 | B.C. | 03201 | P | - | 03281 | 126 | H | 03281 | P | - |
| | 04012 | 132 | H | 03281 | 71 | H | 03201 | 86 | H | 03281 | P | - | 03281 | 79 | H |
| | 04012 | 122 | H | 03281 | 128 | H | 03201 | P | - | 03281 | 150 | H | 03281 | 142 | H |
| Ave. KV | | 133 | | | 144 | | | 73 | | | 110 | | | 78 | |
| % Below 110-KV | | 20 | | | 10 | | | 80 | | | 40 | | | 60 | |

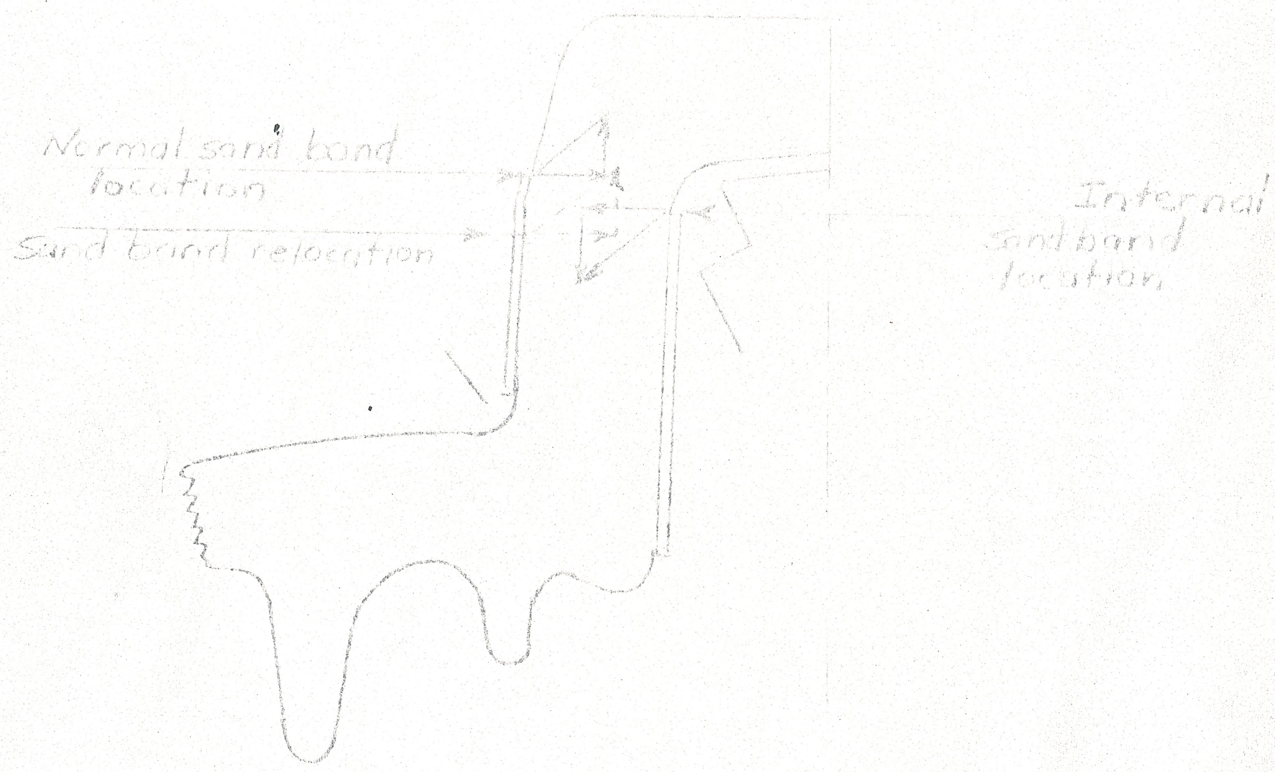
No Pilot Groups

H - Head
B.C. - Base of Cap
P - Puncture under impulse

| | Quantity Tested | No. of Failures | Percent | Average KV |
|---|---|---|---|---|
| | | No. 3 Sand | | |
| Prefired | 10 | 1 | 10% | 66 |
| Prefired | 10 | 9 | 90% | 96 |
| Prefired, Filter Pressed | 10 | 7 | 70% | 86 |
| Filter Pressed | 10 | 6 | 60% | - |
| | | Beryl Compositions | | |
| Raw | 10 | 9 | 90% | 47 |
| Prefired | 10 | 4 | 40% | 124 |
| Prefired, Filter Pressed | 10 | 8 | 80% | 72 |
| 45% Beryl Porcelain, Dry Mix | 10 | 8 | 80% | 73 |
| 45% Beryl Porcelain, Raw | 10 | 6 | 60% | 78 |
| 45% Beryl Porcelain, Raw Dry Mix | 10 | 10 | 100% | 67 |
| | | 317 Compositions | | |
| Raw WG2 | 10 | 2 | 20% | 125 |
| Prefired | 10 | 5 | 50% | 81 |
| 317 and Feldspar, Prefired,Filt.Pressed | 10 | 2 | 20% | 133 |
| 317 and Feldspar, Filter Pressed | 10* | 1 | 10% | 144 |
| 317 and Feldspar, Prefired, Dry Mix | 10 | 4 | 40% | 110 |
| | | Zircon Compositions | | |
| Raw | 10 | 6 | 60% | 100 |
| Raw Zircon and Feldspar | 10 | 4 | 40% | 125 |
| Prefired | 10 | 1 | 10% | 139 |
| Prefired Zircon and Feldspar | 8 | 1 | 12.5% | 149 |
| Prefired | 10 | 3 | 30% | 120 |
| No. 1 | 10 | 3 | 30% | 125 |
| Zircon and Feldspar, Filter Pressed | 10* | 1 | 10% | 144 |

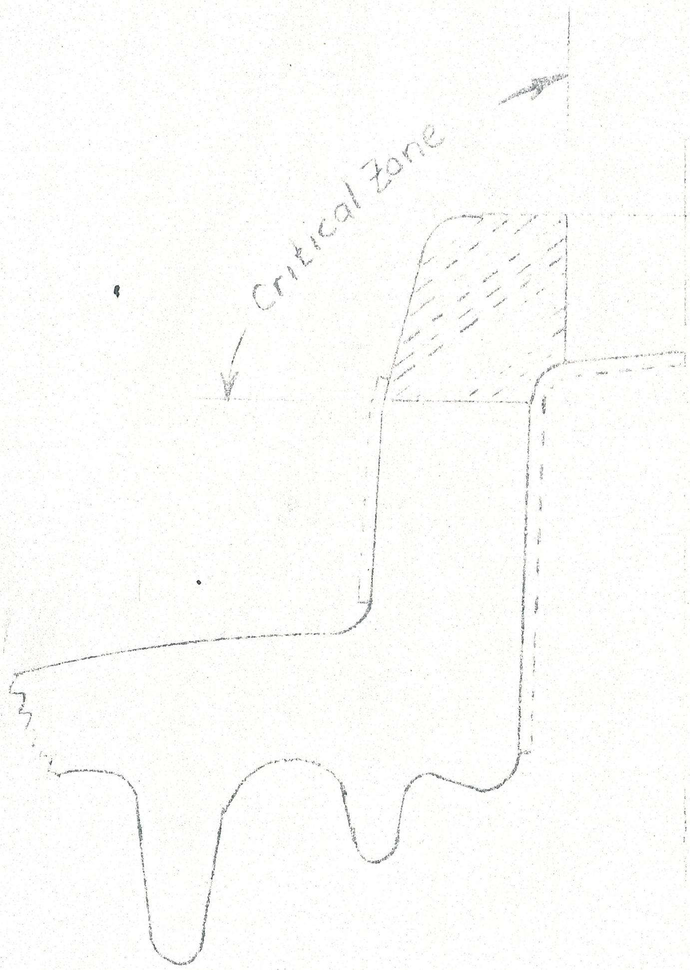
*Same group of insulators

SKETCH
No. I



Normal sand band
location
Sand band relocation
Internal
sand band
location

SKETCH
No 2




Most frequent occurrence of puncture
pitts on impeller and M&E failure
occur in critical zone